Marine Research

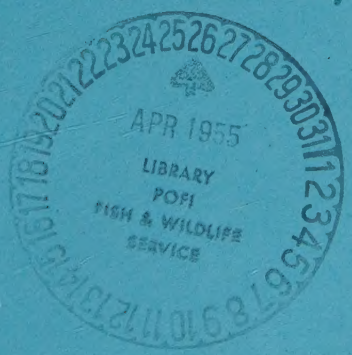
SCOTTISH HOME DEPARTMENT

Marine Research
1952 No. 4

HADDOCK BIONOMICS—1

The State of the Haddock Stocks in the North Sea 1946-50 and at Faroe 1914-50

By B. B. PARRISH, B.Sc. and R. JONES, B.Sc.



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HADDOCK BIONOMICS

I. The State of the Haddock Stocks in the North Sea (1946-50) and at Faroe (1914-50)

Investigations carried out during the past sixty years into the fluctuations in the abundance o major demersal species in European waters have shown the importance of fishing as a contribu factor to the changing yields and catch per unit of effort in this area. These investigations led t formulation of the concepts of "overfishing "and "maximum yield" and provided the stimulus for t developments in the theoretical field from which more precise stock assessments have been made poss The application of theoretical models to fish population problems was first made by Baranov (1918 1925) and it has been extended and modified to cover a larger number of problems, particularl Russell (1939), Graham (1935), Thompson, W.F. (1937 and 1950), Ricker (1940, 1944) and Hu Beverton and Holt (1947). Beverton and Holt are at present engaged in an extensive study of the w subject and we gladly acknowledge the various discussions we have had with them, and particu our knowledge of their adaptation of the Bertalanffy growth equation to fishery problems (pp. 8 and

This paper deals with the assessment of the haddock stocks on the Faroe Plateau and in the N Sea since 1914 and 1946 respectively. It sets out, with the use of simple mathematical models, to d mine the relationship between yield and fishing mortality throughout these periods and to determin present level of yield in relation to the "maximum equilibrium yield". First, however, it is necessa define the terms "overfishing" and "maximum yield" from the biologist's point of view.

Graham (1939b) states that "The productiveness of a fish stock depends on the effort used to ex it, the productiveness first increasing and then decreasing as the effort increases". This statement im that there must be a "maximum fishing intensity" above which the total yield from the fishery decl and it is on this that the concept of *biological* overfishing hinges. By "maximum fishing intensity" is m that fishing intensity which, when operative in a given area, on a self-contained fish stock over a nu of years during which recruitment has been relatively steady, would give the maximum sustained from that area. When the fishing intensity increases above that level which gives rise to the maxi sustained yield from the gear in use then the stock is, on this definition, being "overfished". The pa ular merits of this definition are (1) that it is independent of political or economic factors, which deter the profitableness of fishing to the individual fishermen and which may fluctuate widely from yea year, and (2) that the maximum yield can be determined from population data and is character of each self-contained fish stock subject to commercial exploitation. Necessarily, it depends upon method or methods of fishing.

It is important to note that the simultaneous occurrence of a decrease in the catch per unit of e with the increase in fishing effort is not by itself a reliable indication of the existence of overfishing, s

y increase in effort may tend to result in a decrease in the average stock density, and hence in catch per it, irrespective of whether the yield-effort relationship is above or below the "maximum yield" value. ch decreases are, however, important indications, over a period, of the state of the fishery, and they : of obvious economic significance.

From this definition, it is clear that the detection of biological overfishing from the statistics of a nmercial fishery is possible when, over a period of years during which there has been a steady growth exploitation, the yield is observed to decrease steadily after an initial rise. However, a similar result ıld be produced by a steady reduction in recruitment and/or growth of the fish population, indepen-ıtly of the increase in intensity of exploitation, or even under steady or decreasing exploitation, so t caution must be exercised in the interpretation of commercial statistics alone. For conclusive results, ort must be made to the application of theoretical models to observed population data.

PART I.

THE STATE OF THE HADDOCK STOCKS AT FAROE (1914-50).

Little has been published about the Faroe haddock stock. Thompson (1922), in a paper dealing ı North Sea haddock, gives a small section on Faroe haddock, dealing chiefly with the nature of the es. He considered that the hydrographic conditions at Faroe are relatively uniform and favourable growth, so that winter rings are sometimes omitted or poorly represented on the scales. The scale : suggested growth conditions similar to those prevailing off Iceland, with which stock that at Faroe regarded as being most comparable.

The earliest references to the occurrence of good and bad brood years were also made by Thompson 2 and 1924), who recorded age analyses of haddock for the years 1922 and 1923. Raitt (1936) gave ble of relative brood strengths of Faroe haddock for the years 1916-34, based on data collected by research ships "Dana" and "Explorer".

Parrish (1949) summarised the results from twelve hauls made by "Explorer" at Faroe in June 1947. age and size analyses of the catches are given, and it was found that the average size of each age group greater to the south and west than to the north and east, the largest haddock of all being taken on e Bank.

Commercial Fishery at Faroe

An examination of the total weights of demersal fishes landed annually from Faroe by trawlers of ıtionalities between 1906 and 1939 shows that cod provided by far the greatest weight of any species, t haddock came second in importance. These two species together accounted for 76% of the total ersal fish landed during the period (haddock 18%). British vessels were responsible for much the er proportion of the landings, English trawlers landing 73%, Scottish trawlers 24%, and foreign ers only 3% of the total haddock landings. Since 1939, the Scottish proportion has increased ly, however (Fig. 1).

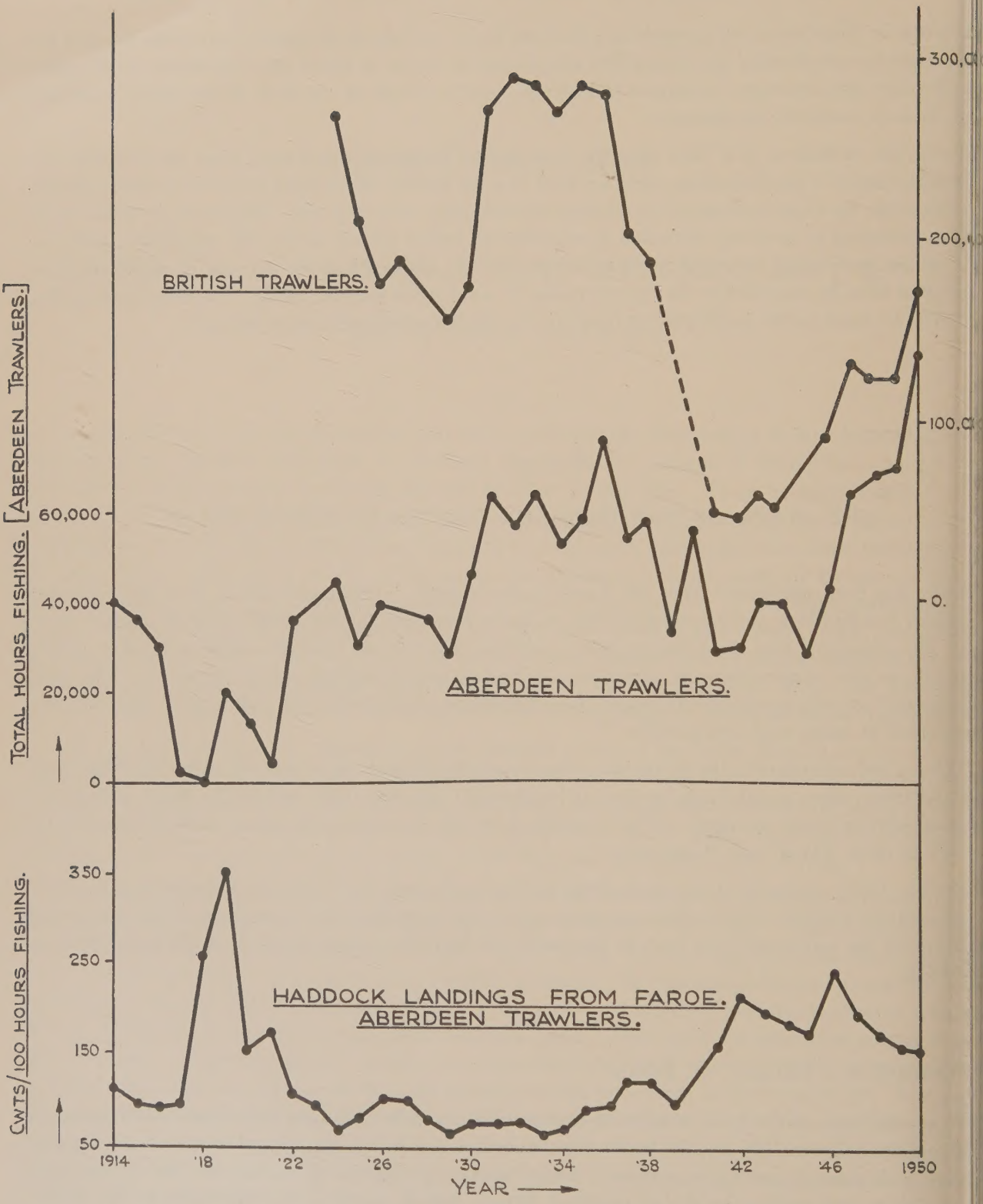


FIG. 1 Annual fluctuations in total hours fishing by Aberdeen trawlers and by all British trawlers and hadd catch/100 hours fishing by Aberdeen trawlers.

E Fishing Grounds

The principal fishing grounds at Faroe are around the north end of the islands, extending from ggenaes in the west round to Nolso in the east. A more limited amount of fishing is carried out to south, on the east and west sides of Sando, to the west of the north end of Sydero, and off Sumbo it and the Monk rock at the southern tip of Sydero.

Between 1936 and 1948, 46% of trips by Aberdeen trawlers to Faroe included fishing off Fuglo er at the north-east of the islands. Other grounds were fished less intensively. English trawlers on other hand have tended to concentrate to the west of the islands off Myggenaes where their heavier is more suitable for the rough bottoms encountered. Between 1941 and 1945, 48% of trips by English lers included fishing off Myggenaes, whilst only 29% were off Fuglo.

UAL Fluctuations in the Landings

Figure 1 shows the mean catch per 100 hours fishing and the total fishing hours spent at Faroe by deen trawlers for each year of the period 1914-1950. The corresponding information concerning s' fishing by English trawlers is not available for the whole of this period, and accordingly the graph n for British trawlers is incomplete.

The annual total of fishing hours by Aberdeen trawlers fell from 40,000 in 1914 to less than 2,000 18. A marked increase then occurred, reaching a maximum of 76,000 hours in 1936. A gradual ne to about 30,000 hours followed during the second world war, after which there was an increase ,000 hours during 1950. A somewhat similar trend took place in the total annual fishing hours nglish and Scottish trawlers combined during the periods 1924-37 and 1941-47, for which periods are available although the English effort has decreased proportionately since the beginning of the

The fluctuations in the catch per 100 hours fishing taken by Aberdeen trawlers is also shown in e 1. There were two maxima, the first occurring in 1918 and 1919, when a value of 300-350 cwts. 00 hours was obtained, which fell off to the still relatively high figure of 160 cwts. in 1920 and 1921. rly steady yield of 60-80 cwts. then followed, up to 1934, after which a second increase gradually place, reaching a maximum of 240 cwts. per 100 hours in 1946.

Comparison with the catches per hundred hours fishing by English trawlers during the period 1924- owed fairly good agreement, these values fluctuating around the 80 cwt. level with a small rise to wts. in 1927, and a larger rise to 125 cwts. in 1937. The two main peaks in the fishery occurred: st after the first world war, and (2) during the second world war.

NG Intensity and Catch per Unit Effort

The most useful index of average stock density during any year that is available to the fisheries gist is "catch per unit effort". Effort may be measured in various ways, but for a fleet of trawlers of arable tonnage and fishing power, the number of hours actually spent in fishing is most preferable. data are not available for all British trawlers fishing Faroese waters, since data relating to hours' g by English trawlers were not collected before 1922, or for the period 1938-41. Consequently, the al fluctuations in catch per 100 hours fishing by Aberdeen trawlers alone has been presented as an of annual fluctuations in the stock density of haddock in Faroese waters during the period 1914-1950. Aberdeen trawling fleet, consisting of a considerable number of ships of more or less comparable ge and fishing power, forms a sampling unit that may be regarded as suitable for this purpose, igh it should be remembered that a slight bias may be caused by the fact that these ships fish princi- around the north and north east parts of the plateau. The English trawlers, on the other hand, ended to spend more time fishing on the north and west sides. Although their share in the fishery nded to decrease, in recent years, it was still contributing more than half of the total British trawler at Faroe in 1950.

As an index of relative fluctuations in total fishing effort each year at Faroe from 1922 onwards, the n records are almost complete (see Fig. 1), but prior to that date only the Scottish effort may be pre-

sented. Of the English fishery during the years of the first world war, we can only say from yield that its intensity must have been reduced proportionately as much as the Scottish fishery, whilst its r at the end of the war, to judge from landings, was as large.

Corresponding with the trends in the catches per hundred hours fishing each year, there w inverse trend in the total hours fishing (Fig. 1).

The degree of correlation between each annual total of fishing hours and the catch per hu hours in (*a*) the same, and (*b*) the following years, was estimated as —0.408 and —0.528 respectivel is evident that lower fishing intensities have been associated with higher catches per unit effort ar *versa*. This correlation would appear to be more marked between fishing effort and catch per unit in the succeeding year.

The most pronounced peaks in the catches per hundred hours fishing by Aberdeen trawlers occ during 1918-19 and 1941-47. In the former instance the catch per hundred hours fishing rose to a of about three times that prevailing in 1914-16. In the latter period it rose gradually to 2·6 time for the period 1930-36. During each of these periods, the fishing effort was at a greatly reduced but in the second case the trough was reached more gradually and was not so deep.

In order to relate fishing effort and catch per unit effort in a more concise manner, a theor approach is essential. The fitting of mathematical models applicable to stocks of fish exploited in v ways has already been considered in some detail, and several workers (*e.g.* Baranov 1918 and 192 Ricker, 1940) have demonstrated that under conditions of equilibrium (*i.e.* constant rates of recruit growth, fishing and natural mortality) the age frequency distribution of a fish stock ma expressed by the relationship:

$$N.dt = Re^{-(F + M)t} . dt.$$

where R = annual number of recruits entering the fishery continuously at age

$N.dt$ = Number of fish lying between ages $t \pm \frac{1}{2}dt$.

F = Instantaneous rate of fishing mortality.

M = „ „ „ natural „

and if Z = „ „ „ total „

$Z = F + M$

and $N.dt = Re^{-Zt} . dt.$ . . . . . (1)

Now, if we also have a suitable expression for the average weight of a fish of age $t \pm \frac{1}{2} dt$, which m represented as $w = f(t)$, then the total weight of all fish lying between ages $t \pm \frac{1}{2} dt$ may be exp by the relationship $W = f(t)\ Re^{-Zt} . dt.$

Clearly the function $f(t)$ should fit a typical weight/age curve of the fish concerned, so that any expr that gives a good fit and is easy to manipulate mathematically will suffice. Hulme, Beverton and (1947) used a linear weight/age relationship of the form $f(t) = (a + bt)$ but since this curve te infinity instead of some asymptotic value as t tends to infinity, Beverton and Holt (MS)* have recently adopted a growth curve of the form

$$f(t) = W_\infty \left[1 - e^{-K(t-t_0)}\right]^3$$

This is simply the cubic form of a supposed length/age relationship of the form

$$\text{Length at age } t = L_\infty \left[1 - e^{-K(t-t_0)}\right] . . . . . (2)$$

The incorporation of the above expression for $f(t)$ in the general equation

$W = f(t)\ Re^{-Zt} . dt.$ and its integration over the ran

*We are grateful for their kindness in allowing us to see their MS. in advance of publication.

encountered in the commercially exploitable portion of the stock, follows logically. These steps being dealt with in considerable detail by Beverton and Holt and only the briefest descriptions will given in the following pages.

The first stage, that of fitting the above length/age relationship; equation (. . . 2), to Faroe haddock , was applied by trial and error to data collected by F. R. S. "Explorer" during the period 1923-1949. values of the constants found were: $L_\infty = 83{\cdot}6$, $K = 0{\cdot}21$, and the resultant curve is shown in 2. The cubic form of this curve may be written:

$$W = W_\infty \left[1 - e^{-0{\cdot}21t}\right]^3$$

In the general expression quoted above (. . . . . 1), R is the annual number of recruits entering the at age 0.

It is now more convenient to consider a number of R^1 recruits, that enter the commercially exploitable at an age p, which may most conveniently be taken as the average age at which 50% of the fish etained and 50% released by the meshes of the codend in use on commercial trawlers.

Equation (1) may now be rewritten as

$$N.dt = R^1 e^{-Z(t-p)}.\ dt. \quad . \ . \ . \ . \ . \ . \ . \ . \quad (3)$$

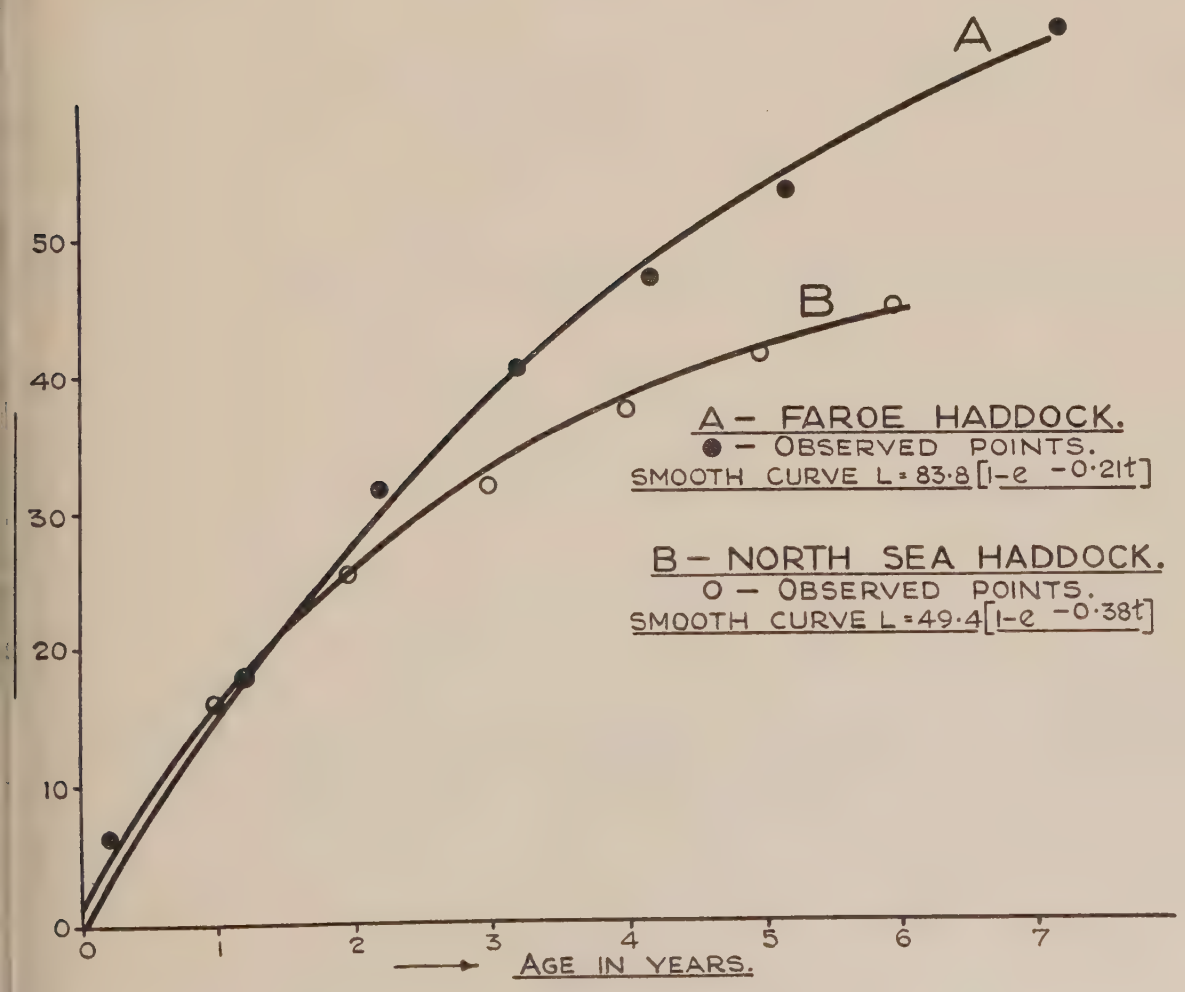


FIG. 2 Generalised age/length relationship of North Sea and Faroe haddock.

PERIOD 1914-1919:

During the period 1914-1919 there was not only a considerable increase in the catch per 100 fishing of haddock from Faroe, but also a sudden sharp drop in the fishing effort during the period 1918. It is necessary to determine whether this decrease in fishing effort was of sufficient magnitu bring about the increase in the observed catch per unit of effort, it being assumed that growth rat recruitment remained constant over the whole period. Before doing this, a suitable expression is rec for describing the effect of a sudden change in fishing intensity on an "ideal stock" previously in equilib This may be derived as follows:

Z_1 and Z_2 are to be defined as the instantaneous rates of total mortality, before and after this ch T years after the change, equation (3) above giving the number of fish of age t, may be replaced b separate expressions, according to whether t is greater or less than $T + p$. These are:

$$R^1 e^{-Z_2(t-p)} . \, dt \quad . \quad . \quad . \quad . \quad . \quad p \leqslant t \leqslant T + p.$$

$$R^1 e^{-Z_1(t-p-T)} \, e^{-Z_2 T} . \, dt \quad . \quad . \quad . \quad T + p \leqslant T \leqslant \infty .$$

Hence by multiplying these expressions by that for weight—

$$W \propto \left[1 - e^{-0 \cdot 21 t} \right]^3$$

—and integrating over all values of t, we have an expression for the total weight of commercially ex able fish, T years after the change in mortality rate from Z_1 to Z_2. Let this weight be S_1.

$$\text{Then } S_1 = R^1 W \propto \int_p^{T+p} e^{-Z_2(t-p)} \left[1 - e^{-0 \cdot 21 t} \right]^3 . \, dt$$

$$+ R^1 W \propto \int_{T+p}^{\infty} e^{+T(Z_1 - Z_2) + Z_1 p - Z_1 t} \left[1 - e^{-0 \cdot 21 t} \right]^3 . \, dt.$$

In order to determine the average weight S_1 during the interval T_1 —T_2 years after the change in mor rate, it is merely necessary to integrate this expression with respect to T over the range $T_1 - T_2$ divide the answer by $(T_2 - T_1)$ thus:

$$S_1 = \frac{1}{(T_2 - T_1)} \int_{T_1}^{T_2} S_1 \, dT.$$

is is equal to:

$$\bar{S}_1 = \frac{R^1 W \alpha}{T_2 - T_1} \left\{ (T_2 - T_1) \left[\frac{1}{Z_2} - \frac{3e^{-0\cdot21p}}{Z_2+0\cdot21} + \frac{3e^{-0\cdot42p}}{Z_2+0\cdot42} - \frac{e^{-0\cdot63p}}{Z_2+0\cdot63} \right] \right.$$

$$\left. \frac{\left(e^{-Z_2T_1} - e^{-Z_2T_2}\right)}{Z_2} \left[\frac{1}{Z_2} - \frac{1}{Z_1} \right] + \frac{3e^{-0\cdot21p}\left(e^{-(Z_2+0\cdot21)T_1} - e^{-(Z_2+0\cdot21)T_2}\right)}{Z_2 + 0\cdot21} \right. \quad . \quad . \quad .$$

$$. \quad . \left[\frac{1}{Z_2+0\cdot21} - \frac{1}{Z_1+0\cdot21} \right] - \frac{3e^{-0\cdot42}\left(e^{-(Z_2+0\cdot42)T_1} - e^{-(Z_2+0\cdot42)T_2}\right)}{Z_2 + 0\cdot42} \quad . \quad . \quad .$$

$$. \quad . \left[\frac{1}{Z_2+0\cdot42} - \frac{1}{Z_1+0\cdot42} \right] + \frac{e^{-0\cdot63}\left(e^{-(Z_2+0\cdot63)T_1} - e^{-(Z_2+0\cdot63)T_2}\right)}{Z_2 + 0\cdot63} \quad . \quad . \quad .$$

$$. \quad . \left[\frac{1}{Z_2+0\cdot63} - \frac{1}{Z_1+0\cdot63} \right] \right\} \quad . \quad . \quad .

During the period 1917-18 the average annual number of hours fishing dropped to 6,741 hours so t
F_2, the fishing mortality rate during this period, may be estimated as:—

$$F_2 = \frac{0{\cdot}612 \times 6741}{35904} = 0{\cdot}115$$

It will now be assumed that the natural mortality rate rose to 17% annually corresponding to
instantaneous rate of 0·18. To summarise these steps, we have:

$$F_1 = 0{\cdot}612; \qquad M_1 = 0{\cdot}14; \qquad Z_1 = 0{\cdot}752;$$
$$F_2 = 0{\cdot}115; \qquad M_2 = 0{\cdot}18; \qquad Z_2 = 0{\cdot}295.$$

For the years 1918 and 1919, $T_1 = 1$ year and $T_2 = 3$ years.

Everything is now known for the application of formulæ A and B except p, the average age at wh
the young haddock enter the fishery. This will be taken as 1·53 years, corresponding to a mean len
of 23 cms. (This is actually the minimum landing size operative at that time rather than the age at wh
haddock entered the fishery, which was rather less).

Substituting these figures into formulæ A and B (p. 11) gives

$$\bar{S}_1 = 0{\cdot}2878\ R^1W_\alpha$$

$$\bar{S}_2 = 0{\cdot}1309\ R^1W_\alpha$$

The ratio of these figures, S_1/S_2, gives the required estimate for the expected increase in catch
hundred hours fishing during the years $\frac{1918\text{-}19}{1914\text{-}16}$. This is equal to 2·20.

Since it has been necessary to assume values of M (the natural mortality rate) in these calculati
the work was repeated assuming

(a) $M_1 = 0{\cdot}05$; $M_2 = 0{\cdot}10$; *(b)* $M_1 = 0{\cdot}18$; $M_2 = 0{\cdot}22$;

this gives new values for Z_1 and Z_2

(a) $Z_1 = 0{\cdot}711$; $Z_2 = 0{\cdot}224$; *(b)* $Z_1 = 0{\cdot}711$; $Z_2 = 0{\cdot}331$;

and new estimates for the ratios of catch per unit effort during the years $\frac{1918\text{-}19}{1914\text{-}16}$ of (a) 2·69 and (b) 2·06

It is evident then that fairly large errors in the natural mortality rates have relatively small eff
in this calculation, thus to some extent justifying the use of a value that has necessarily been gues
This should also be true of any errors arising from the use of Bowman's estimate of 1·42 for the rela
effect of V.D. gear.

The theoretical estimates of 2·06; 2·20; and 2·69 agree quite well with the observed ratio of
for the ratio of catches per hundred hours fishing $\frac{1918\text{-}19}{1914\text{-}16}$, and so it is now legitimate to enquire whet
the corresponding increases in the various market categories were of the order expected. The catc
per hundred hours of extra-small, small, medium, large and extra large haddocks landed at Aberd
from Faroe during the period 1914-50 are tabulated in Table 1.

TABLE I

Landings per 100 hours fishing by Aberdeen trawlers at Faroe of different trade categories of Haddock, 1914-1950

	Extra large	Large	Medium	Small	Extra Small
1914	24·3	63·7	13·9	7·8	0·6
1915	27·3	47·9	10·9	9·2	0·1
1916	19·4	44·5	14·9	14·2	0·3
1917	25·2	52·0	8·2	7·2	0·2
1918	27·6	146·4	34·4	47·5	—
1919	145·8	187·9	9·3	8·0	0·1.
1920	63·3	78·6	9·9	3·9	0·1
1921	66·6	81·1	18·6	7·0	0·4
1922	49·0	47·4	3·1	2·5	0·2
1923	34·5	21·2	19·4	20·6	1·3
1924	11·3	33·2	10·8	9·2	1·7
1925	13·2	37·6	11·3	12·7	4·0
1926	19·2	40·4	16·2	19·0	5·8
1927	17·2	37·4	17·0	18·1	8·8
1928	12·6	29·8	15·0	12·0	6·0
1929	12·4	21·5	10·7	8·4	6·7
1930	10·9	16·3	13·3	15·1	17·1
1931	8·6	17·2	13·5	13·8	19·4
1932	9·6	18·0	14·2	15·6	20·7
1933	11·1	14·8	10·2	9·6	15·9
1934	10·8	9·4	8·5	10·5	30·1
1935	11·5	10·6	12·2	15·3	30·4
1936	9·2	10·2	10·2	12·7	48·6
1937	9·5	10·5	14·2	22·0	64·4
1938	11·3	23·9	28·3	23·6	33·2
1939	14·5	27·8	17·4	10·2	26·3
1940	14·0	18·4	14·4	17·6	62·4
1941	17·2	11·7	40·8	17·1†	72·6
1942	15·9		141·1		57·7
1943	16·1		145·2		33·7
1944	23·2		134·3		26·7
1945	39·0		103·0		29·6
1946	8·3		139·6		91·7
1947	9·1		125·5		60·0
1948	30·2	‡	118·0		24·2
1949	18·3		109·8	70·7	*
1950	26·9		53·6	53·6	*

*Extra small not landed when minimum landing size was raised (1948).

†Wartime grouping of categories.

‡Post-war grouping of categories.

Since the precise estimation of the expected increase in each category, following on a decreas fishing effort, would require an increase in the complexity of formulæ A and B to an extent that accuracy of these calculations does not warrant, a graphical method of obtaining these estimates has b employed. This is shown in fig. 3.

Curve A is the theoretical weight/age distribution of commercially exploitable fish during period 1914-16. Curve B shows the same thing for 1918-19. By subdividing the areas beneath t curves into portions representing different size categories of haddock, and estimating the relative a of each category beneath each curve (by plotting on squared paper and counting the squares), expected change in weight (and hence in catch per unit effort) of each category has been evalua These are:—

	Observed ratio (1918-19) / (1914-16)	Theoretical ratio
Extra small	0·3	1·2
Small	1·7	1·7
Medium	2·7	2·3
Extra large and large ..	3·4	2·7
All categories	3·0	2·2

The agreement is quite good except in the case of the extra small category in which the obse figures were much less than the calculated one. This could be explained, however, by the fact tha fishermen at that time did not land many of the extra small fish; in fact, it was not until about 1930 a market was sought for them (Table I).

It may be concluded, then, that the increase in the catch per unit effort of haddock from F during the first world war can be adequately explained by the decrease in fishing effort at the tim

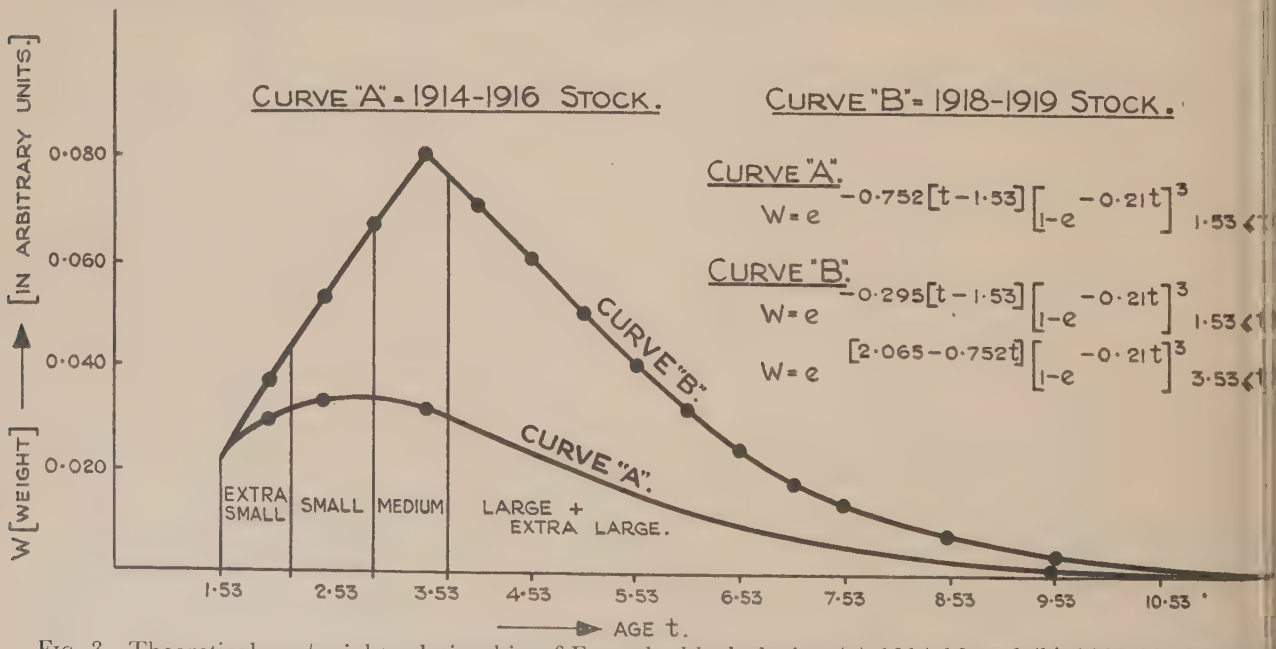


FIG. 3 Theoretical age/weight relationship of Faroe haddock during (a) 1914-16 and (b) 1918-19, from w the expected increase in catch/unit effort of each trade category during the latter period has b estimated.

PERIOD 1934-50

The simple formulæ derived above are not suitable for application to the increase in catch unit effort during the period 1939-46, since the changes in fishing effort took place gradually and

larly over a period of several years. In order to meet these conditions, an extension of the simple ry is shown in the Appendix, where the weight of fish present in any year is expressed as the sum ıe weights of its constituent broods. The weight of each brood has been expressed as a function of recruitment (assumed to be constant), the growth rate, and the mortality rates operative during each of life.

LICATION TO THE PERIOD 1934-50

The first step, before carrying out these computations, is to estimate a value of Z_x for each year veen 1926 and 1950. It has already been pointed out that the average value of Z for the period -1939 was 1·26, and, assuming a value of natural mortality of 0·15, the average value of F for the od may be taken as 1·11.

During the period the average annual hours fishing by English and Scottish trawlers, combined, 230,366 hours, and by equating this value to a value of F of 1·11, values of F_x for each year have estimated proportionally from the hours fishing. The combined fishing hours by both Aberdeen English trawlers have been used in these calculations, apart from the period 1938-41, for which ıates are based on fluctuations in the fishing effort by Aberdeen trawlers alone.

x	F_x	M_x	Z_x	x	F_x	M_x	Z_x
1926	0·85	0·15	1·00	1939	0·79	0·15	0·94
1927	0·92	0·15	1·07	1940	0·80	0·15	0·98
1928	0·84	0·15	0·99	1941	0·25	0·18	0·43
1929	0·76	0·15	0·91	1942	0·23	0·18	0·41
1930	0·85	0·15	1·00	1943	0·30	0·18	0·48
1931	1·32	0·15	1·47	1944	0·26	0·18	0·44
1932	1·41	0·15	1·56	1945	0·21	0·18	0·39
1933	1·39	0·15	1·54	1946	0·45	0·18	0·63
1934	1·31	0·15	1·46	1947	0·64	0·15	0·78
1935	1·39	0·15	1·54	1948	0·59	0·15	0·74
1936	1·37	0·15	1·52	1949	0·60	0·15	0·75
1937	0·99	0·15	1·14	1950	0·84	0·15	0·99
1938	0·93	0·15	1·08				

s been assumed that there was an increase in the natural mortality rate from 0·15 to 0·18 during ·46.

It is further assumed for the purposes of these calculations, that the number of recruits of each l $R^1_{(x-n)}$ are constant, so all that is now required is a value of Y, the interval of time for which a l is being fished, during its first year of life in the fishery.

It has already been pointed out that p, the age on entering the fishery, may be taken as 1·53 (up

to 1948), and since this age is reached, on the average, by Faroe haddock during October of their year of life, Y may be taken as equal to 0·14 years.

Finally, by estimating for each year the weights of each of the constituent broods of haddo average stock density (and hence catch per unit effort) for each year has been estimated for th 1934-47.

During 1948, an increase in the minimum landing size of haddock to 28 cms. (average ag resulted in the rejection of many fish at sea.

An age of 1·94 years is reached by Faroe haddock on the average at the end of February i third calendar year.

This means that the $(x-1)$ brood may be neglected during year x, but that the $(x-2)$ brood big enough to land at an age 1·94 years ($=p'$) and from then on will be subject to fishing for 0·8 during year x ($=Y'$). Since there was no change in mesh size during 1948, these fish will have e the fishery at their usual age of 1·53 years and so for calculating the average weight of the $(x-2)$ of landable size in years subsequent to 1948, the following formula is more appropriate

$$R^1_{(x-2)}\, W \propto e^{\left[\frac{Z_x+Z_{(x-1)}}{2}\right](p'\ p)} \left\{ \frac{1-e^{-Z_x Y'}}{Z_x} - \frac{3e^{-0\cdot21p'}\left(1-e^{-(Z_x+0\cdot2}\right.}{Z_x+0\cdot21} - \right.$$

$$+ \frac{3e^{-0\cdot42p'}\left(1-e^{-(Z_x+0\cdot42)Y'}\right)}{Z_x+0\cdot42} - \frac{e^{-0\cdot63p'}\left(1-e^{-(Z_x+0\cdot63)}\right.}{Z_x+0\cdot63}$$

For broods $(x-n)$, where $n \geqslant 3$, no modification in the general formulæ for $R^1_{(x-n)}\ W_{(x-n)}$, is rec

The results of these calculations are shown in figure 4.

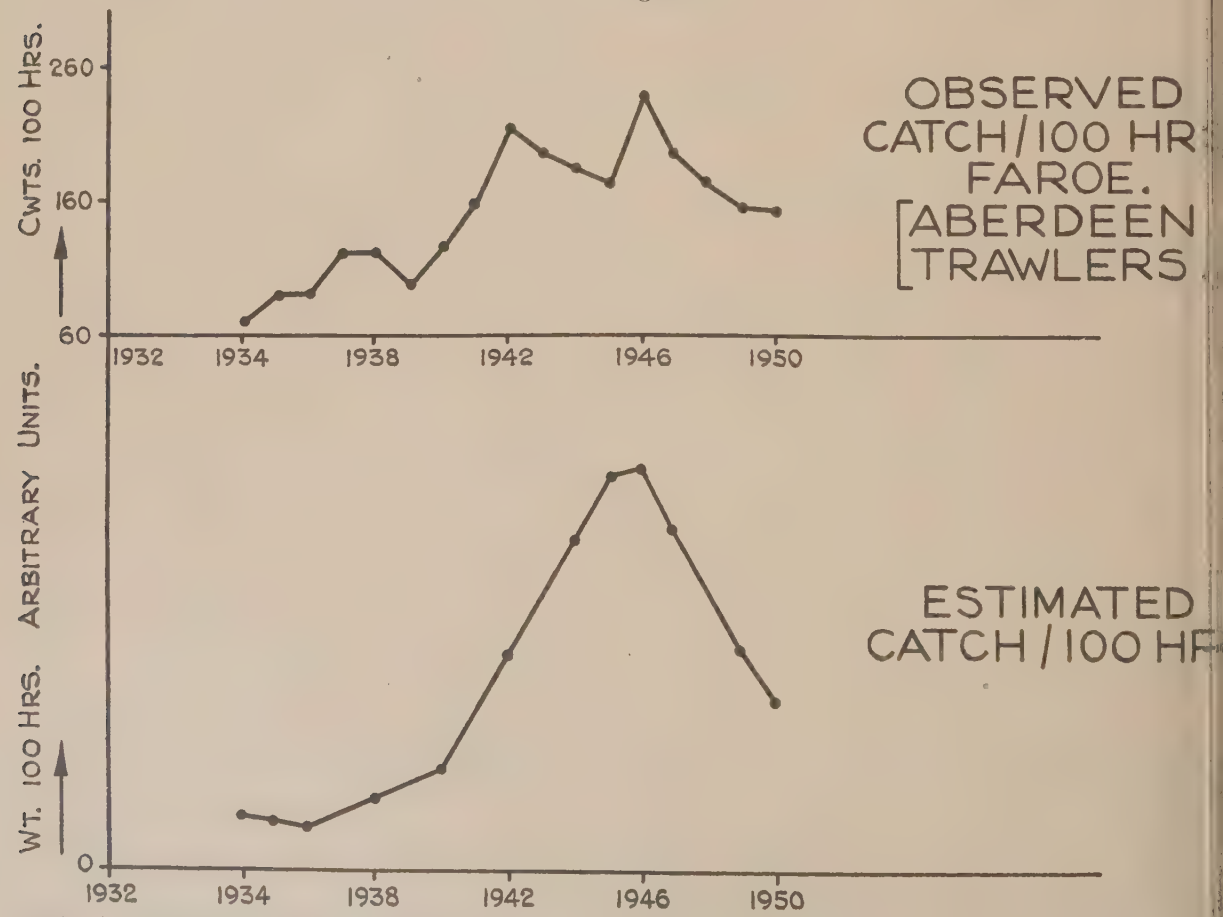


FIG. 4 A comparison of the annual fluctuations in observed and theoretical catch/100 hours of Faroe ha from 1934 to 1950.

t is seen that both observed and theoretical curves give similar pictures, each starting at a relatively evel in 1934, rising gradually at first to 1940, and then more rapidly to reach a maximum in 1946. then shows a rapid decrease up to 1950. There are two prominent differences between these curves, ver, the first being due to a decrease in the observed catch per hundred hours between 1942 and and the second due to the fact that the theoretical increase in catch per hundred hours in 1946 en times the value in 1934, whereas the observed ratio is only 3·2.

It appears, then, that the increased catch obtained at the end of the first war was approximately e order which would have been expected to follow such a reduction in the fishing effort. The sponding catch following the second wartime reduction of fishing was only about half that which d have been expected on similar reasoning.

A comprehensive explanation of this is not at present possible, although a number of factors may played some part. It is quite possible that with an increase in stock density during the war, there decrease in the growth rate of the population and an even greater increase in the natural mortality han that assumed in the calculations. Both of these factors would tend to reduce the actual yield the theoretical estimate for 1946 but not sufficiently to account for the discrepancy observed, s it is assumed that the natural mortality rate increased to 30% or more during the war.

Another important factor is the rejection of fish at sea. From Table I it is clear that in the early the majority of extra small haddocks were rejected at sea. Up to 1924, they had scarcely been considering (those landed were only some 5% of the total), but from then on the quantities landed ased until in 1934 they represented as much as 43% and in 1946, 38% of the total haddock ngs from Faroe. There is, however, some doubt whether the market category "extra-small" in 1946 ne same as that before the war, since it is known that in both 1945 and 1946 Aberdeen vessels fishing North Sea were rejecting most of the haddocks caught below 30 cms. in length. It is quite possible hips fishing at Faroe were doing the same thing, and since the pre-war category "extra-small" was osed principally of haddocks of less than 30 cms. in length, no comparable category could have d in any numbers at the end of the war.

Finally, any falling off in relative brood strengths at the beginning of the war would tend to decrease pected yield in 1946, although at present insufficient evidence is available to test out this effect.

n conclusion it must be realised that none of the above explanations alone are sufficient to explain screpancy between the observed and calculated yields per unit effort in 1946, and it is probable everal or all of these factors have played some part in it. A more precise analysis of these various ilities will, therefore, be made the subject of a future report.

An essential difference from the earlier sequence is that the intensity of fishing (both English and sh) increased far more rapidly after the second war, and it is still increasing. Not only has much benefit in increased stock been lost, but the fall may soon be more striking, as has happened in orth Sea. It is essential therefore, to consider whether the "maximum catch" level has already been l.

MUM YIELD

Owing to annual fluctuations in recruitment, fishing intensity, growth rates, etc., no fishery is ever to reach a true state of equilibrium yet it is clear that if for a period of several years we regard variables as fluctuating about certain mean values, then during that period the annual yield from hery will fluctuate about some mean level. The problem, therefore, is to determine the level of intensity that will give rise to the highest mean annual yield, defined in this manner.

suitable approach to this problem is through the use of formula B. (p. 11). This is an expression weight of commercially exploitable fish present in a stock under conditions of equilibrium when by a given cod-end. By multiplying this expression by F (the instantaneous rate of fishing mortality) mes an expression for annual yield.

ccordingly, all that is now necessary is to plot values of F.S. (the expression for annual yield) t F or Z, to give a picture of the relationship between annual yield and fishing effort (or total lity rate).

This has been done in Fig. 5, assuming values of natural mortality equal to 0·10 and 0·22.

Of course, these curves are not valid over their whole range since, with increase in stock d there will possibly be some decrease in growth rate and increase in natural mortality rate, so t ordinates to the left of the curves are probably over-estimates.

However, this does not affect the conclusion which may obviously be drawn from the curve. is that with an instantaneous rate of mortality of about 1·00 (its present value), one must exp yield to be appreciably less than the theoretical maximum.

Without adequate knowledge of the natural mortality rate, it is not possible to predict the ma fishing intensity very accurately, and at this stage it is only possible to say that the true maximum intensity lies somewhere between the values leading to instantaneous rates of total mortality of 0· 1·0. This being so, and even though it should prove that there is not yet any serious overfishing haddock stock (a matter which is subject to discussion), it remains instructive to consider the ef restricting the total fishing effort to about three-quarters of that in operation in 1950. Calc shows that this may be expected to provide a yield up to 1·24 times the present annual yield anc 1·76 times the catch per unit effort.

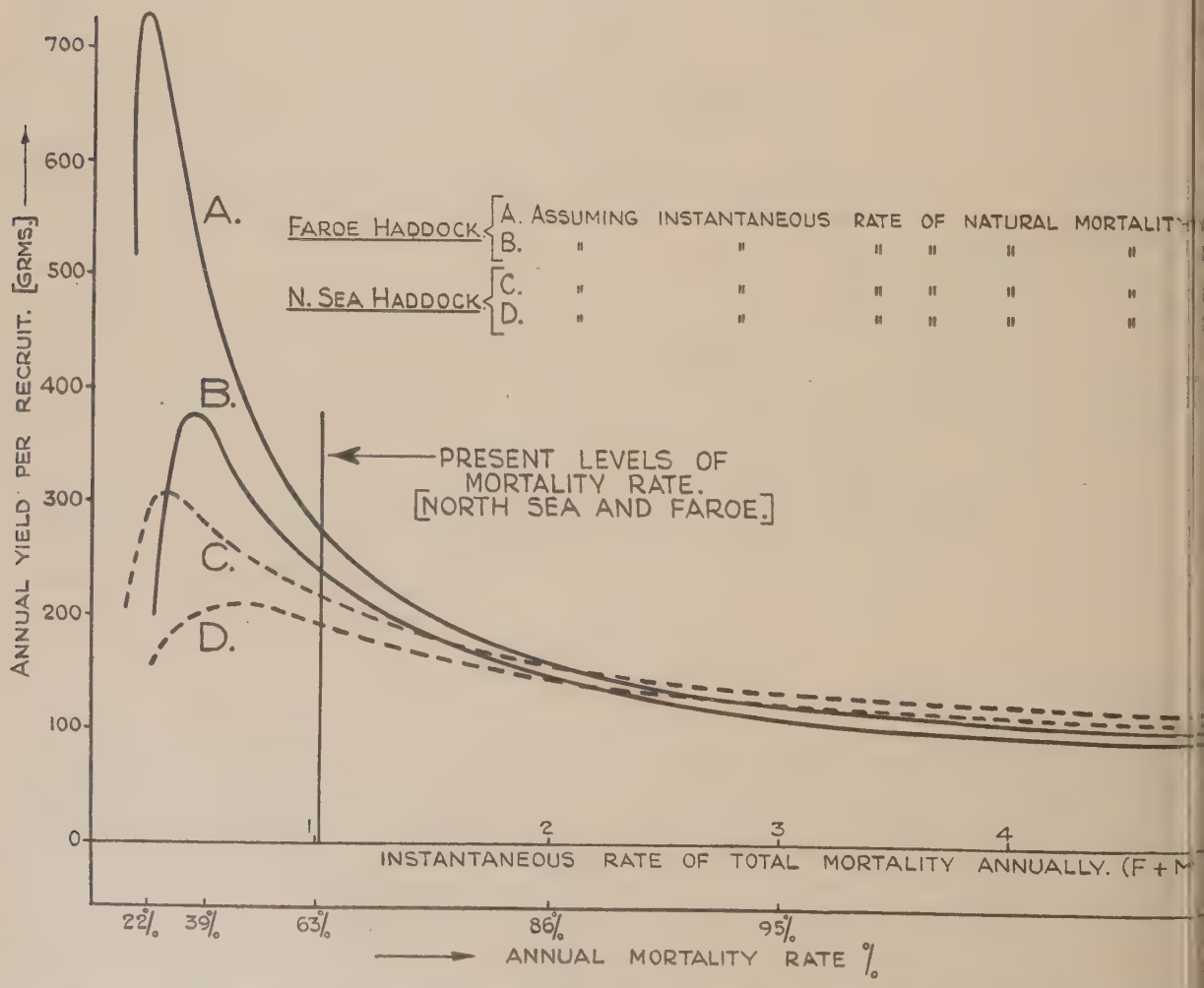


FIG. 5 Generalised relationship between yield and mortality rate in North Sea and Faroe haddock st

These conclusions are by no means confined to the effects of fishing with a 70 mm. cod-end, since ulation shows that any increase in mesh size (at least to 80 mm. or 90 mm.) would ultimately lead to a her improvement in yield. This seems to be true even if the effort were not simultaneously decreased.

Part II

THE POST-WAR HADDOCK STOCKS IN THE NORTH SEA (1946-50)

Investigations carried out during the inter-war years by Raitt (1939) and Russell (1939) into the ogy and population dynamics of the North Sea haddock indicated strongly that these stocks were fished. Evidence for this was obtained from two main sources:—

(1) The available statistics of the combined North Sea haddock fisheries, and in particular the British l fishery, which showed a decline in the total yield and particularly in the yield of the larger commercial categories of fish, and a general fall in the catch per unit of effort during this period.

(2) The analysis of sample catches from the fishing area, which showed a progressive decline in average age and size compositions of the exploitable stocks, resulting during the later inter-war s in a small number of young age-groups upon which the commercial fishery was based.

Thus, despite a lack of detailed knowledge of the total intensity of exploitation of these stocks by uropean countries, these workers were able to establish fairly conclusively that the North Sea haddock ries in the late inter-war period were operating at an intensity greater than that required to give naximum sustained yield. This was supported by the results obtained following the wartime respite ng the years 1940 to 1945, when the weight density of haddock in the North Sea was found to have ased greatly over its pre-war value (Parrish, 1948; Margetts and Holt, 1948), due largely to a greater dance of the larger size categories in the stock. Following the re-opening of the fishing grounds 45, however, the intensity of exploitation of the haddock stocks developed rapidly with the result the stock density and catch per unit of effort dropped from the high 1945 level. An analysis of lation data collected since 1945 has been made, therefore, to determine the stock composition density during 1946-1950, and to gauge the relationship between the present fishing mortality rate h is determined directly by the effective intensity of exploitation) and that required to give the mum yield.

Composition of the Stock

Raitt (1939) found that the increase in the rate of exploitation of the pre-war haddock stock was panied by a decrease in the age composition of the exploitable population, which in the immediate ar years was composed almost entirely of fish of less than five years of age, with the result that the y was based mainly upon young, actively growing, fish.

The age composition of the post-war stock has been determined, as in pre-war years, from the ing surveys of the research vessel *Explorer*. The results of these surveys are contained in Table II, gives the average annual catch of each age-group per 10 hours fishing and the percentage age- osition. Data for 1946 and 1947 are presented separately but, so as to reduce the influence of fluctuations, mean estimates are presented for the years 1948 to 1950 and, for comparison, for the ar years 1937 to 1939. Figures for 1945 are also given, but these refer to the age-analysis of hercial trawler landings, since no research vessels were operating in that year.

TABLE II

Age Composition of North Sea Haddock stock in pre-war and post-war periods

Age Group	1937-39		1945		1946		1947		1948-50
	No. per 10 hours	%	No. per 10 hours	%	No. per 10 hours	%	No. per 10 hours	%	No. per 10 hours
1	455	30·9	240*	9·6	1,982	58·2	24	1·6	529
2	633	42·9	1,235	49·3	1,093	32·1	1,184	79·3	202
3	305	20·7	423	16·9	215	6·3	220	14·7	188
4	63	4·3	131	5·2	50	1·5	42	2·8	91
5	7	0·5	153	6·1	21	0·6	10	0·7	34
6 and older	12	0·7	324	12·9	43	1·3	13	0·9	7
TOTAL ..	1,475		2,506		3,404		1,493		1,051

*Figures for 1 group not representative of true density in population due to mesh selection (commercial trawl).

Despite annual variations in relative brood strength which bias year to year comparisons, results show clearly the reduction since 1945 in the numbers of fish in the older age categories. Fu they show that the age composition in the years 1948-1950 was similar to that in the pre-war p

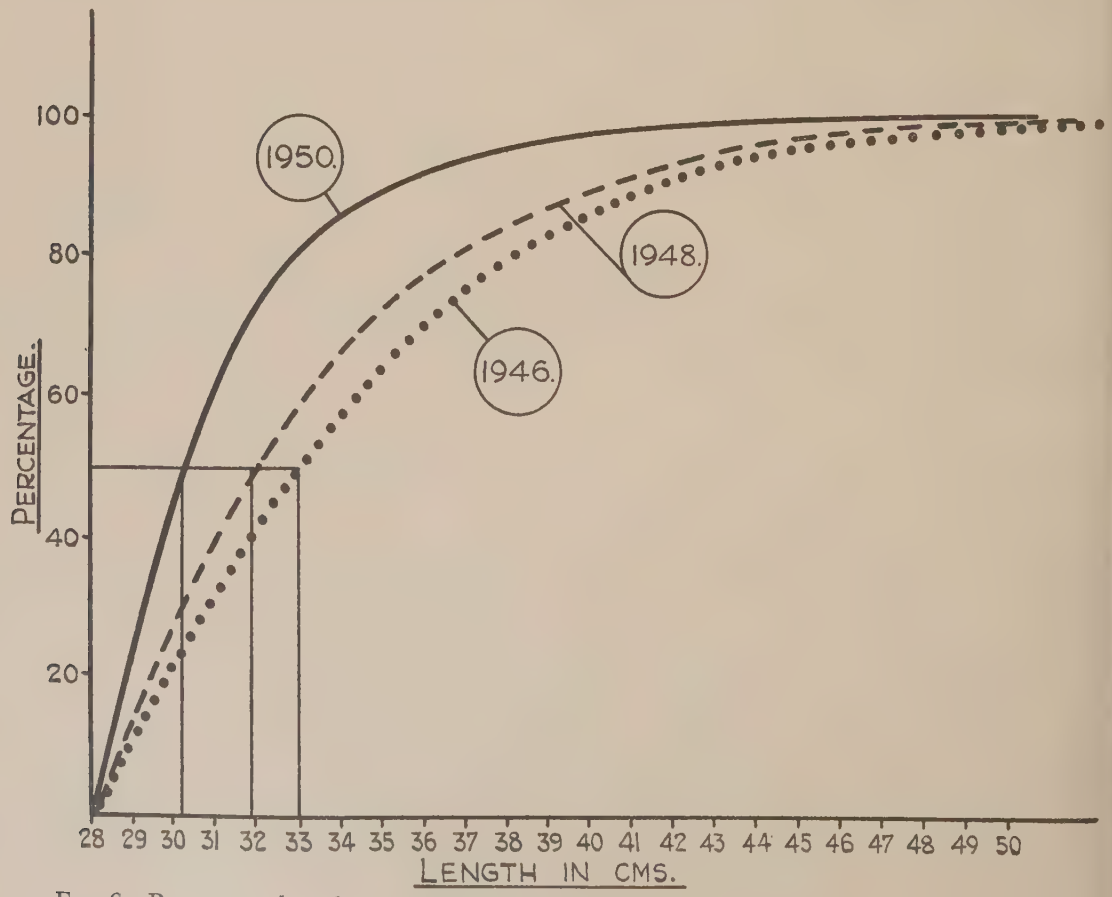


FIG. 6 Percentage length compositions of North Sea haddock in 1946, 1948 and 1950.

act, the number density in these post-war years was less than pre-war, but this was due primarily ne occurrence in 1946 and 1947 of two successive poor brood survival years.

The reduction in stock density since 1945 is further illustrated in Figure 6 which gives the percentage th distributions of fish caught above the minimum marketable size of 28 cms. (11 inches) in each ne post-war years. These data show that the exploitable stock during the post-war period was reduced ze to become composed in 1950 of fish mainly less than 40 centimetres in length.

TISTICS OF THE POST-WAR FISHERY

In the absence of published statistics of catch and effort for all countries exploiting the North Sea dock stocks a complete assessment of the growth of the post-war fishery cannot be made, and the se of events must be gauged from the statistics of the British trawl fishery*, for which complete are available since 1946. These are presented in Table III for the post-war years 1946 to 1950, for the pre-war period 1930-1938.

TABLE III

British Steam Trawler Landings of Haddock from the North Sea, 1930-1938 and 1946-1950

Year	Total Weight Landed (1,000's of cwts.)	Total Hours Fishing (1,000's of Hours)	Weight Landed per 100 Hours (Cwts.)
1930	1,741·6	2,649·3	65·7
1931	1,434·4	2,435·4	58·9
1932	1,365·1	2,322·9	58·8
1933	1,516·2	2,607·6	58·2
1934	1,185·2	2,711·5	43·7
1935	955·5	2,630·2	36·3
1936	745·4	2,475·6	30·1
1937	956·7	2,231·2	42·9
1938	999·2	1,956·0	51·1
1946	697·5	881·3	79·1
1947	831·0	1,072·8	77·4
1948	689·6	1,163·8	59·3
1949	510·7	1,079·6	47·3
1950	523·8	1,070·5	48·9

The important features which these statistics reveal may be summarised as follows.

(1) Since 1947 the British post-war trawl fishery has become stabilised at approximately half its e-war intensity of exploitation.

(2) The post-war period has been marked by a steady decline in the catch per unit of effort to reach 1949 and 1950 a value approximately the same as that obtained in the immediate pre-war period.

From (2) and the stock analyses discussed above, it is evident that since 1945 the weight density e post-war stock has fallen to approximately its pre-war value, despite a much smaller intensity of oitation by British trawlers. It might be concluded, therefore, that the proportion of the total ng effort on the North Sea haddock stock by British trawlers had fallen considerably from its pre-war . Data are not available to estimate this proportion, but it is known (Bulletin Statistique) that the

*Catching some 60-70% of the total yield of North Sea haddock.

British proportion of the whole North Sea catch of trawled haddock had decreased only slightly, 72% in 1938 to 62% in 1947. It is, therefore, necessary to consider the other major contribution to Sea fishing, Scottish seine netting. The yield from this has increased steadily for over twenty but particularly since 1938, when it produced some 50,000 cwts.; in contrast it produced 400,000 in after which there was a decrease to 200,000 in 1949. Over this period, in fact, Scottish seine-n has produced about one-quarter of the British catch of North Sea haddock, and as much as one- in some years. This additional catch, in conjunction with a temporary stock depression due to tw year classes† in 1946 and 1947 (Parrish, 1950), seems adequate to account for the continued f unit catch. Since total effort data are not available for all haddock fisheries operating in the Nort since the war, no further conclusions can be reached from the commercial statistics.

Application of Population Models to Data

The results given above show that the stock density of haddock in the North Sea has been re since 1945 to approximately its pre-war level, and suggest that a marked increase in the total and catch per unit of effort cannot be expected until the intensity of exploitation is reduced. How these data by themselves cannot be used to demonstrate the existence of overfishing, and it is not po from them to determine the extent of the change in exploitation necessary to give the maximum sust yield. This can only be approached by the application of fishing theory techniques to observed popul data. This is possible, using the simple yield equation given in Part I of this paper using values of mortality and growth rate applicable to the North Sea haddock stock in post-war years.

Annual Mortality Rate

For the accurate solution of the yield equation, measures are required of the instantaneous of fishing and natural mortalities operating in the North Sea haddock stocks during the post-war p Separate estimates of these measures cannot be made from the existing data but estimates of the com mortality rate can be calculated. These are derived from the age composition data collected duri course of the trawling cruises by the research vessel *Explorer* in the North Sea during the years 19 1950. Regression techniques have been applied to the logarithms of the numbers of each age passing through the fishery during the post-war period. Details of this method are presented else (Parrish, 1950). This analysis gave a best estimate of 1·02 for the instantaneous rate of total mor during the post-war period (64% annual mortality). No significant change in this rate could be det during this period, and the differences between the estimates for the different age-groups were all st cally non-significant. The value of 1·02 was accordingly accepted as the pooled estimate for all classes wholly within the exploitable stock.

A comparable measure of the total annual mortality rate during the inter-war period was not ava before the war, although Raitt (1939) showed that the percentage survival of the exploited age-g was of a low order. Recalculation of his data by the methods described above gave a measure annual mortality rate as 1·04 during the late inter-war years. It is evident, therefore, that the po stock is subject to approximately the same rate of mortality as in pre-war years.

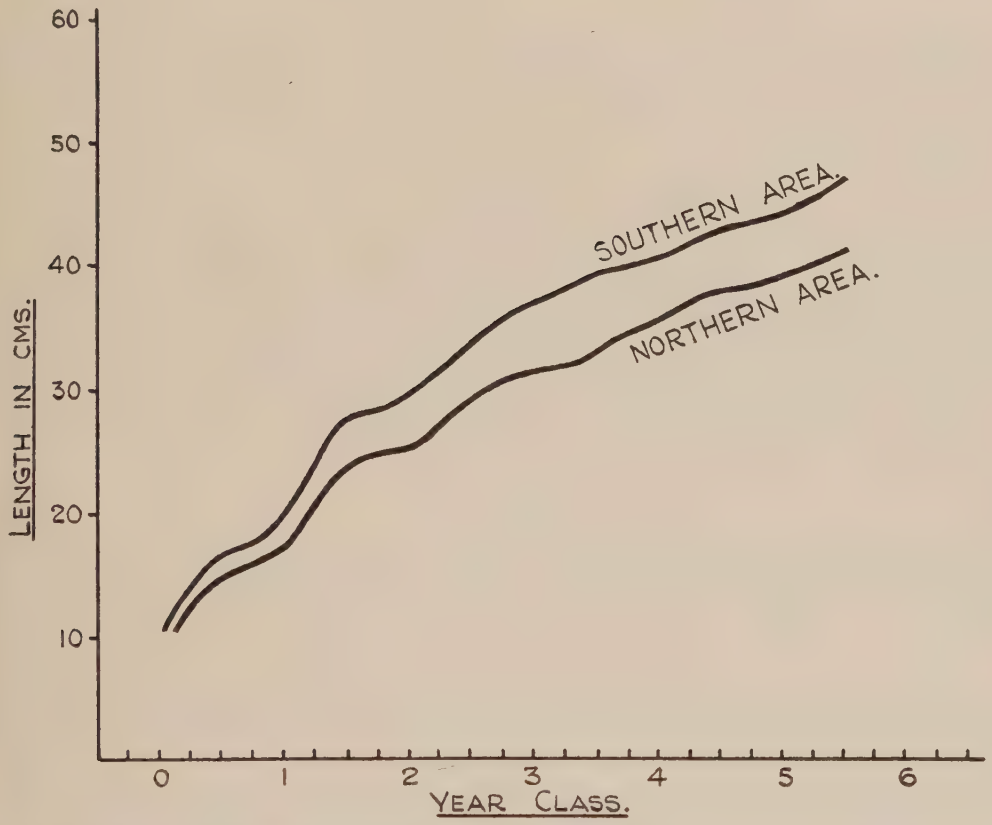
Growth Rate

The second measure required for the solution of the yield equation is an expression to describ rate of growth in weight of the haddock population. This can also be determined from the age and l data obtained during the course of research vessel trawling surveys in the North Sea. Figure 7 mean growth curves for haddock in the North Sea from 1946 to 1950 for the areas to the north south of latitude 57°30′N, which line subdivides roughly the areas of fast and slow growth. The

†Which undoubtedly contributed largely to the greatly decreased seine-net catch of 1949.

hs of each age group at the end of each year of life in the two areas, determined from the curves, s follows.

	Mean Length		
Age	*Northern Area*	*Southern Area*	*Mean Estimate*
1	15·5	17·8	16·0
2	25·0	28·0	26·0
3	30·5	34·5	32·0
4	34·5	40·0	37·5
5	38·0	43·0	41·5
6	41·5	48·5	45·0



Comparison of the age/length relationship of haddock from the southern and northern areas of the North Sea.

nean estimates of length from the North Sea weighted according to the relative stock density in o areas are plotted in Figure 2, in which the best fitting growth curve is also given. The form of urve calculated from these data is as follows:—

$$L_t = 49{\cdot}4\ \left(1-e^{-0{\cdot}38t}\right)$$

tionship Between Total Yield and Fishing Mortality Rate

he relationship between total yield and the rate of fishing mortality has been determined by ng the data above in equation (B), p. 11, and multiplying by F. Constant rates of natural lity and growth rate have been assumed over the whole range of fishing mortalities considered

and, in the absence of real measures of the rate of natural mortality operating in the ha stock, calculations of the expected yield have been made between the natural mortality rate lir 0·10 (10% annual mortality) and 0·22 (20% annual mortality). The calculated relative yields ov range of values of fishing mortality between 0 and 5·0 are presented graphically in Figure 5 whic shows the present level of the total mortality rate in operation in the North Sea.

From this illustration, it is evident that the present intensity of exploitation, which determir rate of fishing mortality, has reached a level greater than that required to give the maximum sus yield. On the evidence available, it appears that a reduction in fishing mortality rate to a valu between 0·20-0·40 would be required to attain this. But it must be borne in mind that this es is made on the assumption that the rates of growth and natural mortality remain unchanged ov relative stock density levels indicated in Figure 5, the validity of which cannot at present be acc assessed.

Finally, these calculations have been made on the assumption of a constant mesh size exploiting gear and refer to the age at which 50% of the fish are first caught (and released) by th when using a 70 mm. mesh in the cod-end of the gear. Recalculation of the yields on the pr 80 mm. mesh basis, however, does not affect the relationship between the present rate of mortali the maximum value on the yield curve.

It is clear that only with a knowledge of the total effective intensity of exploitation of the Sea haddock stocks can Figure 5 become a yield-effort curve, from which the reduction in in of exploitation necessary to give the maximum sustained yield can be properly assessed. This c be done until full statistics of the exploitation by each fishing method and each country become ava so that the determination of mortality per unit effort can be ascertained. The provision of such co statistics of yield and effort for the whole European fishery is an urgent necessity, for the complet uation of the stocks. They provide the basis not only for the assessment of the stock in relation to f but also for assessing the results of legislative measures introduced to rationalise fishing.

SUMMARY

This paper deals with the assessment of the haddock stocks on the Faroe Plateau and in the Sea since 1914 and 1946 respectively and is set out in two parts, each of which is summarised belo

Part I.

1. Over the period 1906-1939, 97% of the haddock landings from Faroe were made by British tra The most important demersal species, by weight, was the cod, which contributed 58% of th landings. Haddock contributed 18%.

2. The fishing grounds at Faroe are principally around the north end of the islands, extending Myggenaes in the west round to Nolso in the east. A certain amount of fishing is carried out to the on the east and west sides of Sando, to the west of the north end of Sydero, and off Sumbo Light a Monk Rock at the southern tip of Sydero.

3. Annual fluctuations in fishing effort, and catch per 100 hours fishing over the period, are rev and a theoretical formulation of a possible relationship between these quantities is presented. this approach, it is shown that—

(a) During the period 1914-1919, the increase in catch/unit effort at the end of the war m adequately explained in terms of the decrease in fishing effort at the time.

(b) For the period 1934-1950 the increase in catch/unit in 1946 was only about half that which have been expected on similar reasoning. Possible explanations for this discrepancy are conside

4. The relationship between maximum yield and annual mortality rate for the Faroe haddock is calculated on the assumption that the growth rate is unaffected by change in population density that instantaneous natural mortality rate is of the order of 0·10 to 0·22.

rom these considerations, it is concluded that with the mortality rate operating in 1950 (instantaneous of 1·14) one must expect the yield to be appreciably less than the theoretical maximum.

II.

l) Since 1945 there has been a reduction in the size and age compositions of the North Sea haddock to reach in 1948-1950 its low pre-war level.

?) The total annual mortality rate over the period 1947-1950 has been constant at approximately nd equal to its value in the immediate pre-war years.

i) The catch per unit of effort of British steam trawlers declined after 1946 to reach in 1949 and he pre-war level.

k) That the post-war stocks are overfished (as defined on p. 4) is indicated from the derived ishing mortality curve.

APPENDIX

xtension of the simple theory developed in the text to meet the case of a series of changes in fishing ity from year to year.

et $R^1_{(x-1)}$ be the number of recruits of a brood $(x-1)$ entering the fishery during the year x. As before, e the age of these fish on entering the fishery, and let Y be the interval of time (as a fraction of a year) apses from then until the end of year x.

hen, at any moment t, during year x, the weight of brood $(x-1)$ will be given by

$$R^1_{(x-1)}\ W \propto\ e^{-Z_x t}\left(1-e^{-0\cdot21(t+p)}\right)^3.\ dt.$$

Z_x is the instantaneous rate of mortality during year x. The average weight of the brood during the whole ll therefore be given by

$$R^1_{(x-1)}\ W \propto \int_0^Y e^{-Z_x t}\left(1-e^{-0\cdot21(t+p)}\right)^3.\ dt.$$

$$= R^1_{(x-1)}\ W \propto \left\{\frac{1-e^{-Z_x Y}}{Z_x} - \frac{3e^{\ 0\cdot21p}\left(1-e^{-(Z_x+0\cdot21)Y}\right)}{Z_x+0\cdot21}\right.$$

$$\left. + \frac{3e^{-0\cdot42p}\left(1-e^{-(Z_x+0\cdot42)Y}\right)}{Z_x+0\cdot42} - \frac{e^{-0\cdot63p}\left(1-e^{-(Z_x+0\cdot63)Y}\right)}{Z_x+0\cdot63}\right\}$$

nvenience this may be presented by $R^1_{(x-1)}\,\overline{W}_{(x-1)}$.

nilarly, at any moment, t, during year x, the weight of any other brood, $(x-n)$ say, will be given by

$$R^1_{(x-n)}\ W \propto\ exp\ -\left(YZ_{(x\ n+1)} + \sum_{i=1}^{n-2} Z_{(x\ i)}\right)\left[1-e^{-0\cdot21(t+p+Y+n-2)}\right]^3 e^{-Z_x t}.\ dt.$$

and its average weight by

$$R^1_{(x-n)}\ W \propto exp\ -\left(YZ_{(x-n+1)} + \sum_{i=1}^{n-2} Z_{(x-i)}\right)\left[\frac{1-e^{-Z_x}}{Z_x} - \frac{3e^{-0\cdot21h}\left(1-e^{-(Z_x+0\cdot21)}\right)}{Z_x + 0\cdot21}\right.$$

$$\left. + \frac{3e^{-0\cdot42h}\left(1-e^{-(Z_x+0\cdot42)}\right)}{Z_x + 0\cdot42} - \frac{e^{-0\cdot63h}\left(1-e^{-(Z_x+0\cdot63)}\right)}{Z_x + 0\cdot63}\right]$$

This may be represented by $R^1_{(x-1)}\ W_{(x-n)}$ where $n \geqslant 2$ provided that when $n=2$, $\sum_{i=1}^{0}$ is regarded as ze $h=p+Y+n-2$.

Finally, by summing the weights of each brood, an expression is obtained for the average total we commercially exploitable fish during year x. This may be expressed as

$$R^1_{(x-1)}\ \bar{W}_{(x-1)} + \sum_{n=2}^{y} R^1_{(x-n)}\ \bar{W}_{(x-n)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (C)$$

where y is an age at which the numbers and weight of a brood have become negligible.

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